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USING SLURRY COMPOSITIONS****Publication Classification**

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(57) **ABSTRACT**

In a slurry composition for chemical mechanical polishing, a method of preparing the slurry composition and a method of polishing an object using the slurry composition, the slurry composition includes a cerium oxide abrasive particle having a rare earth element other than cerium as a dopant, and an aqueous medium for dispersing the cerium oxide abrasive particle. The cerium oxide abrasive particle doped with the rare earth element may have an enhanced fracture strength as being compared with a pure cerium oxide abrasive particle, and also may reduce an amount of large or agglomerated particles and generation of a scratch on a polished surface of an object.

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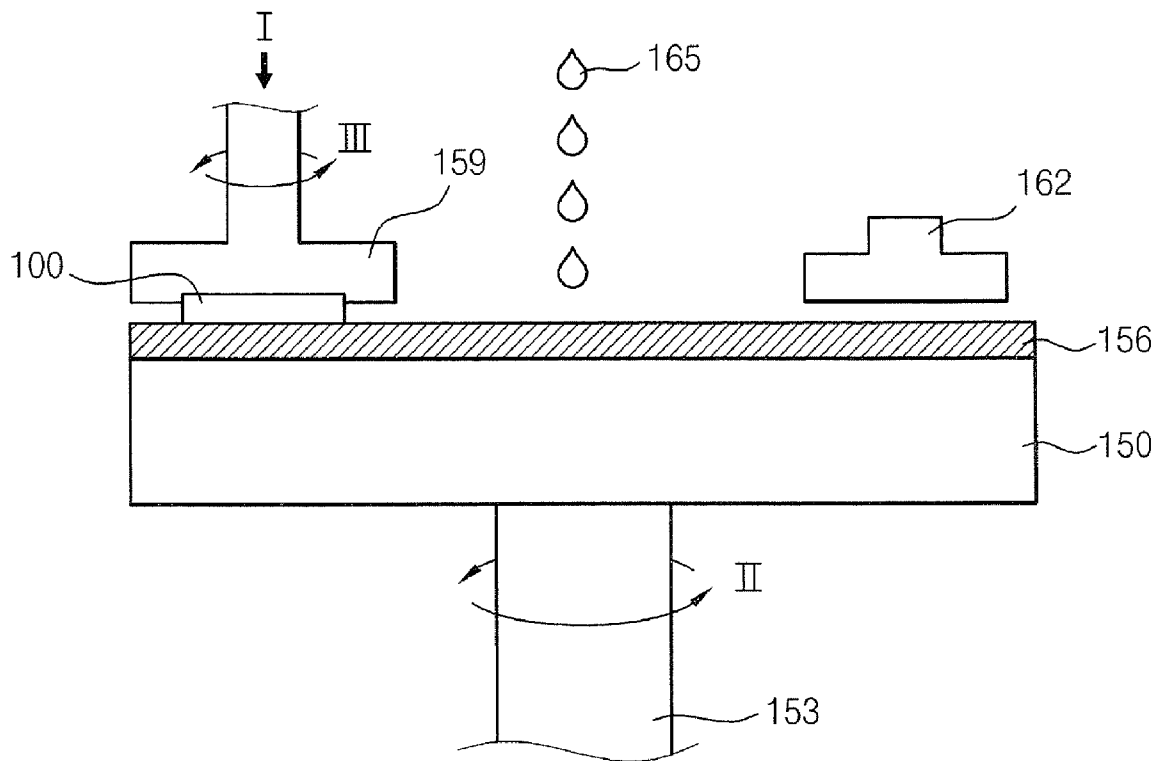


FIG. 1

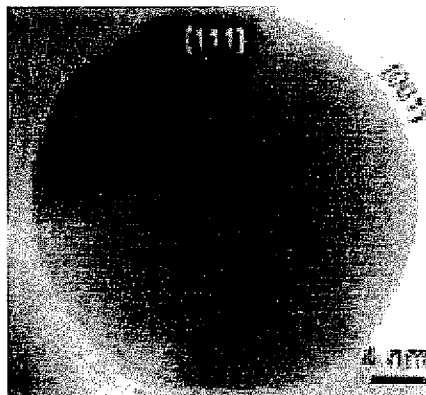


FIG. 2

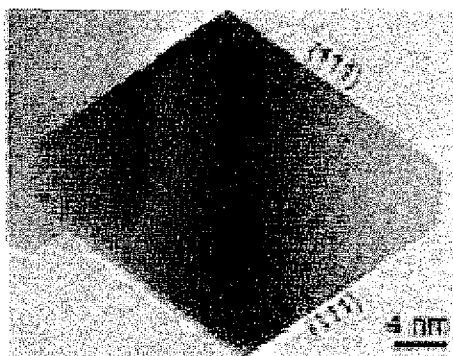


FIG. 3

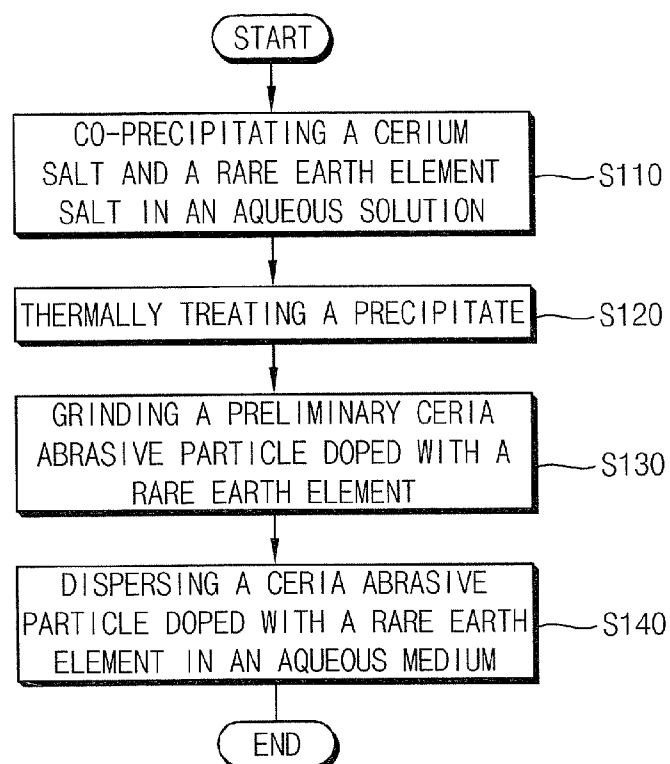


FIG. 4

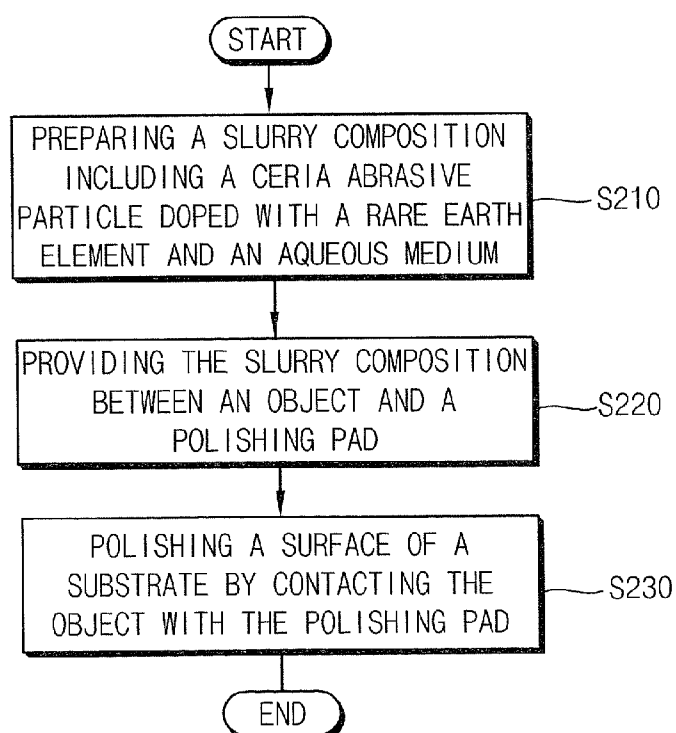


FIG. 5

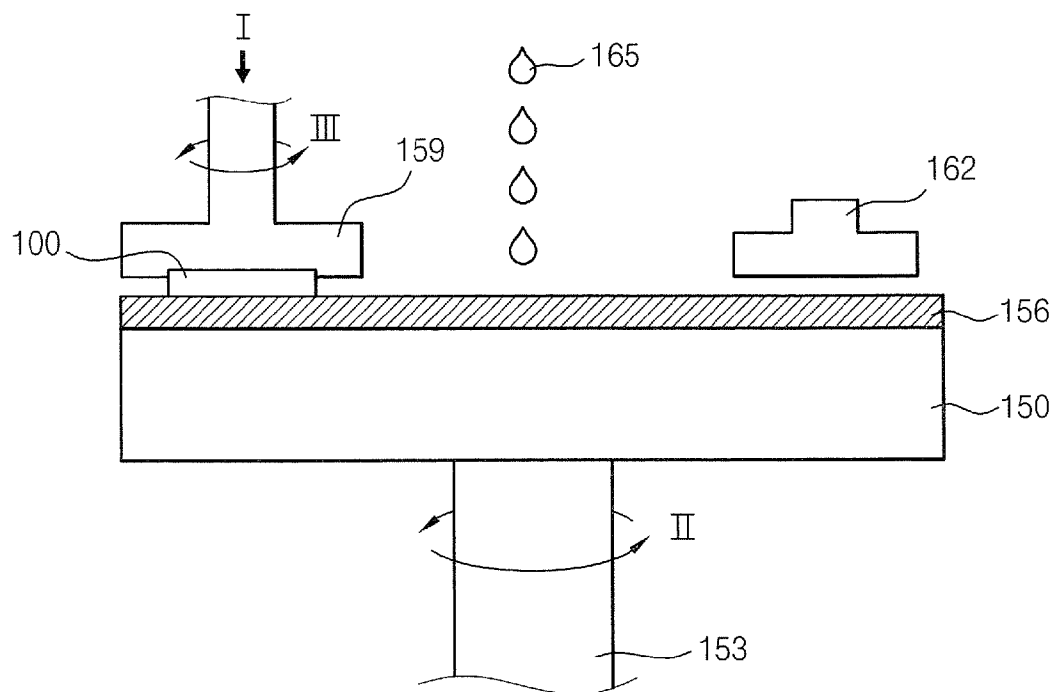


FIG. 6A

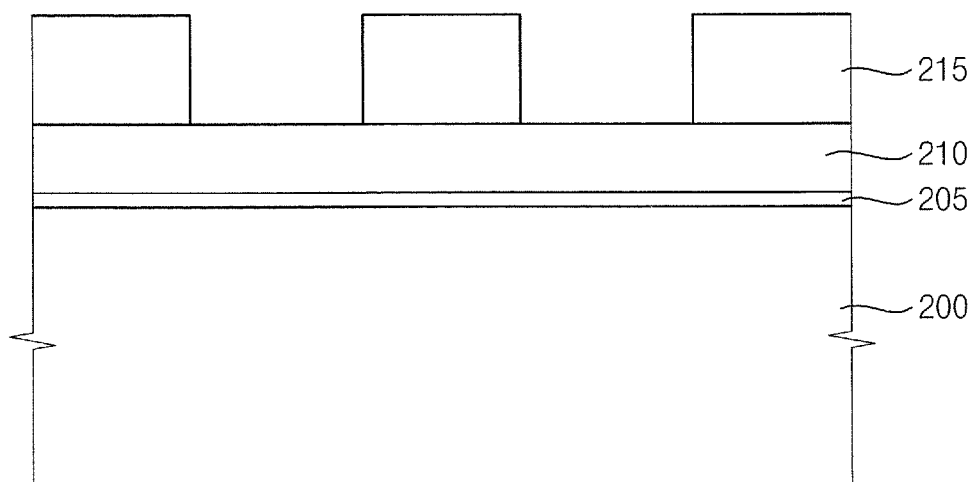


FIG. 6B

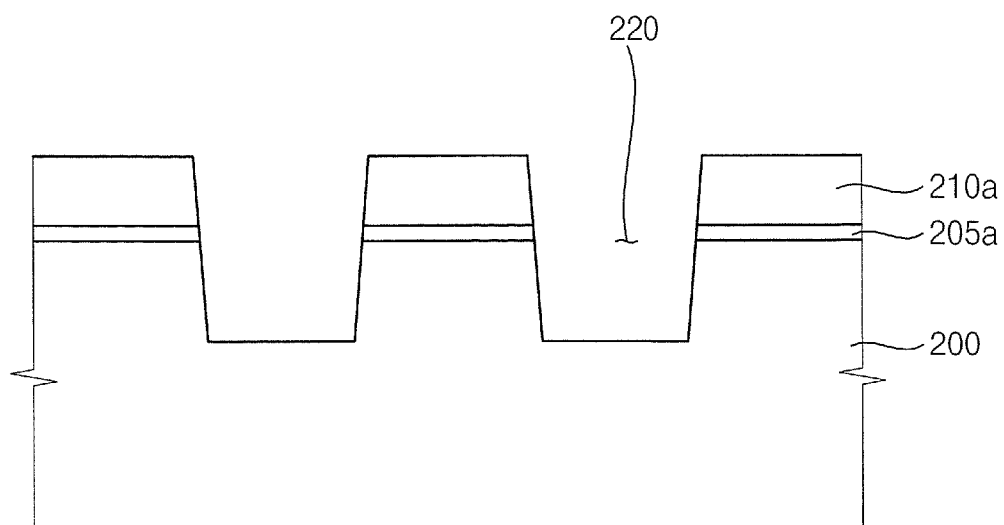


FIG. 6C

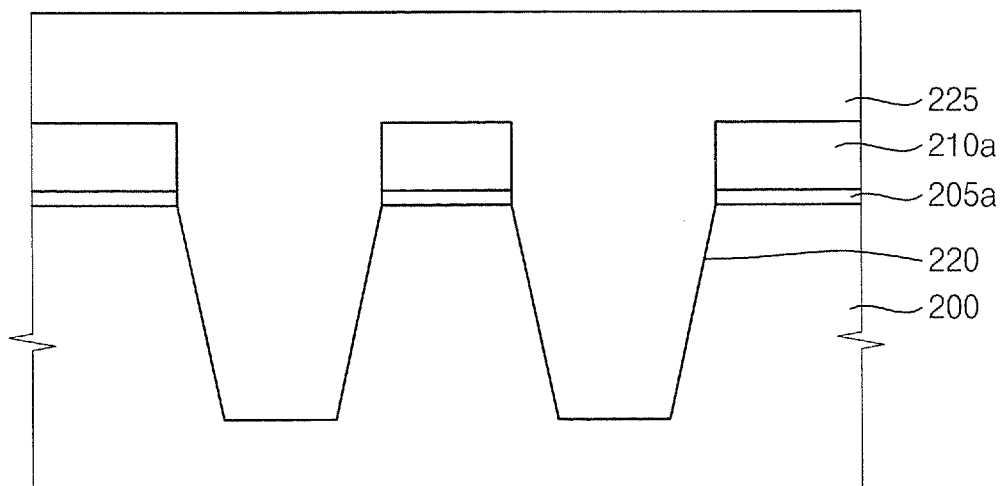


FIG. 6D

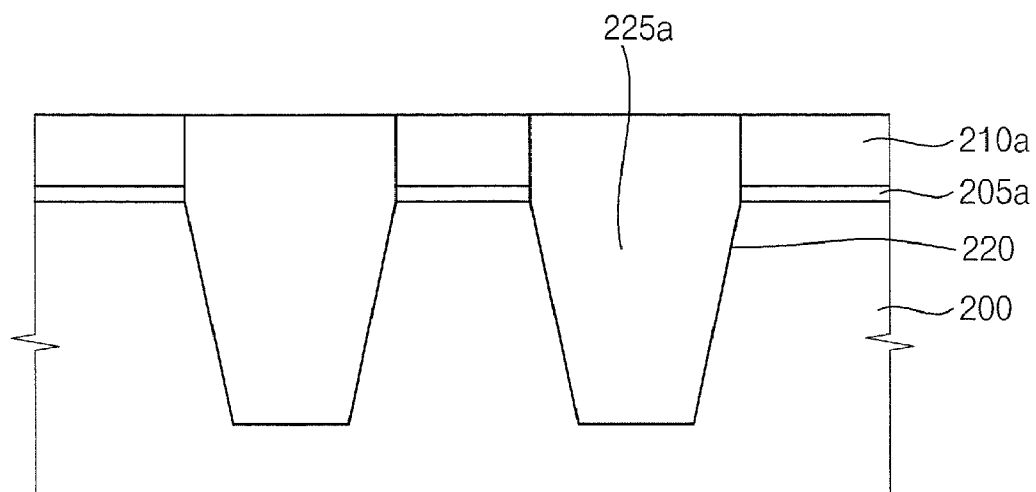


FIG. 7A

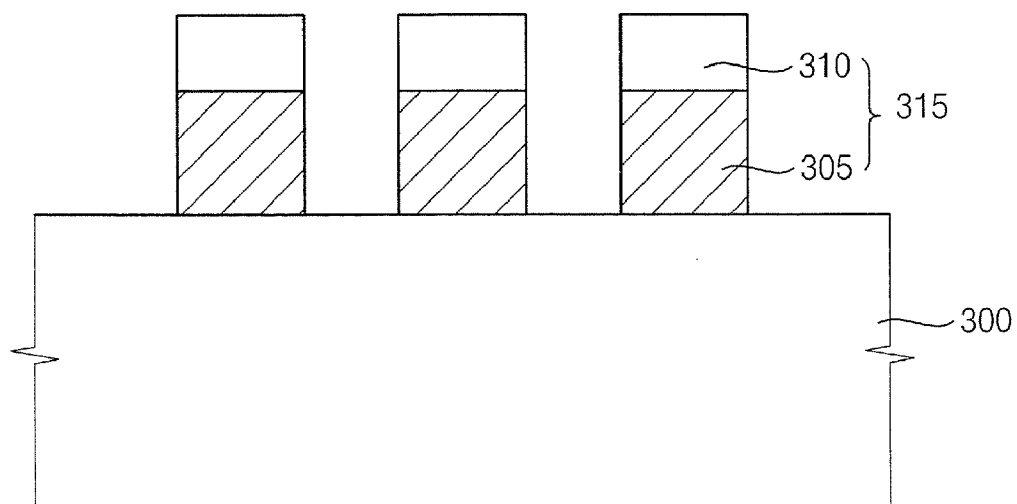


FIG. 7B

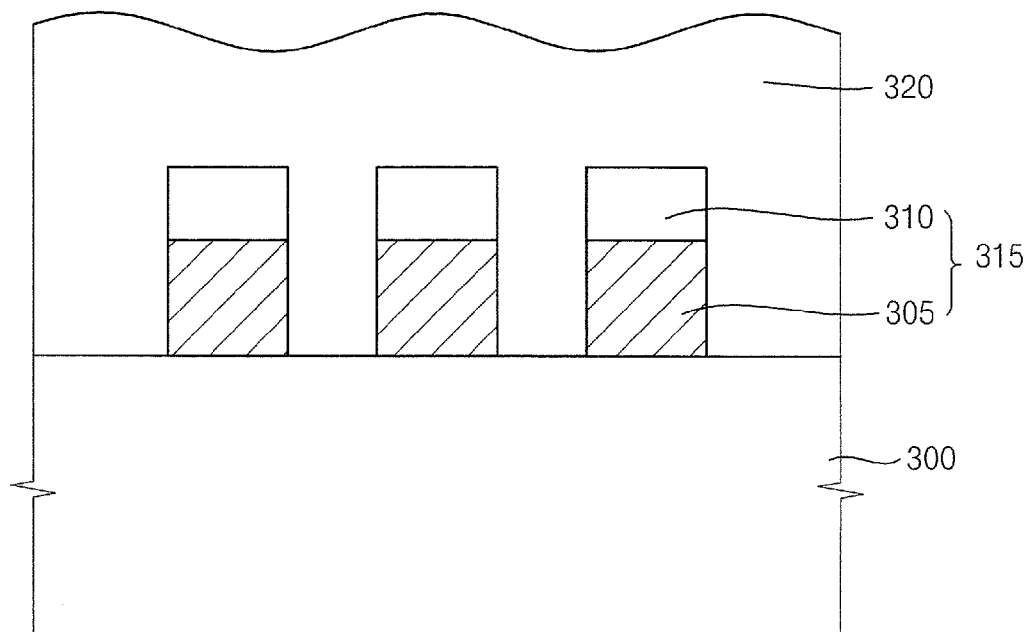


FIG. 7C

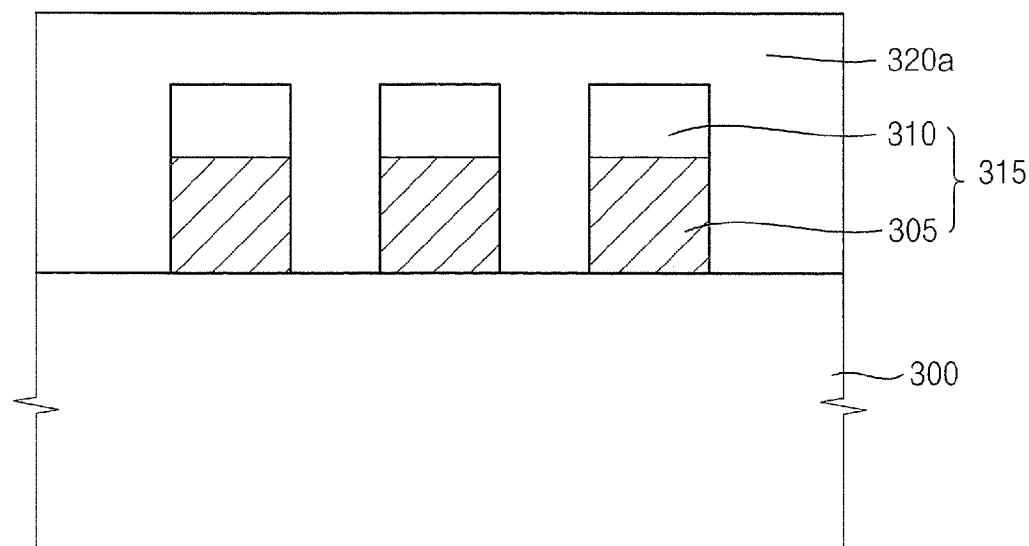


FIG. 8

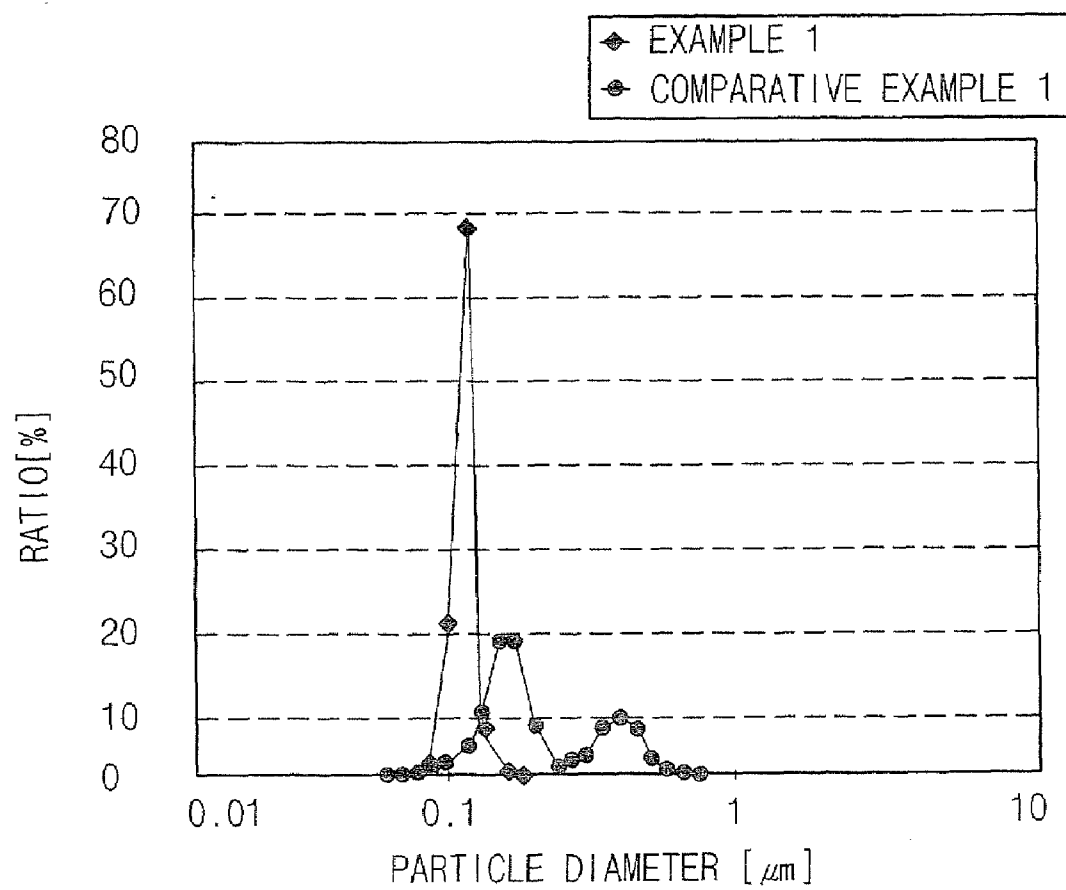


FIG. 9

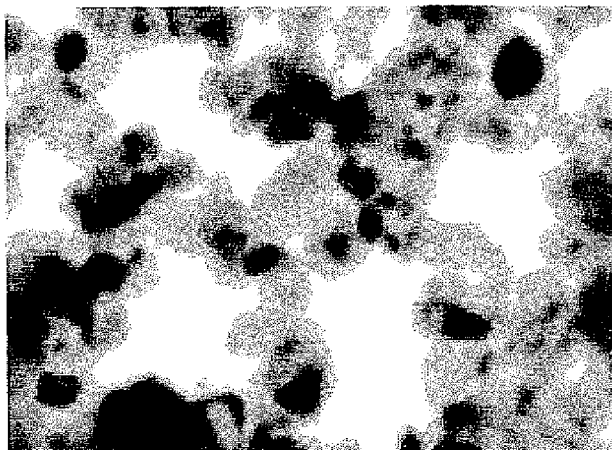


FIG. 10

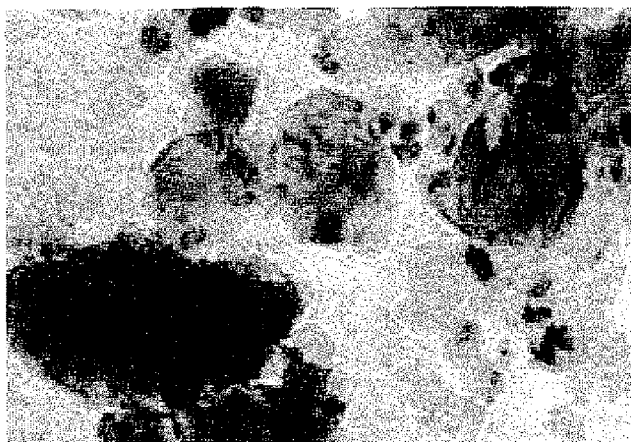


FIG. 11

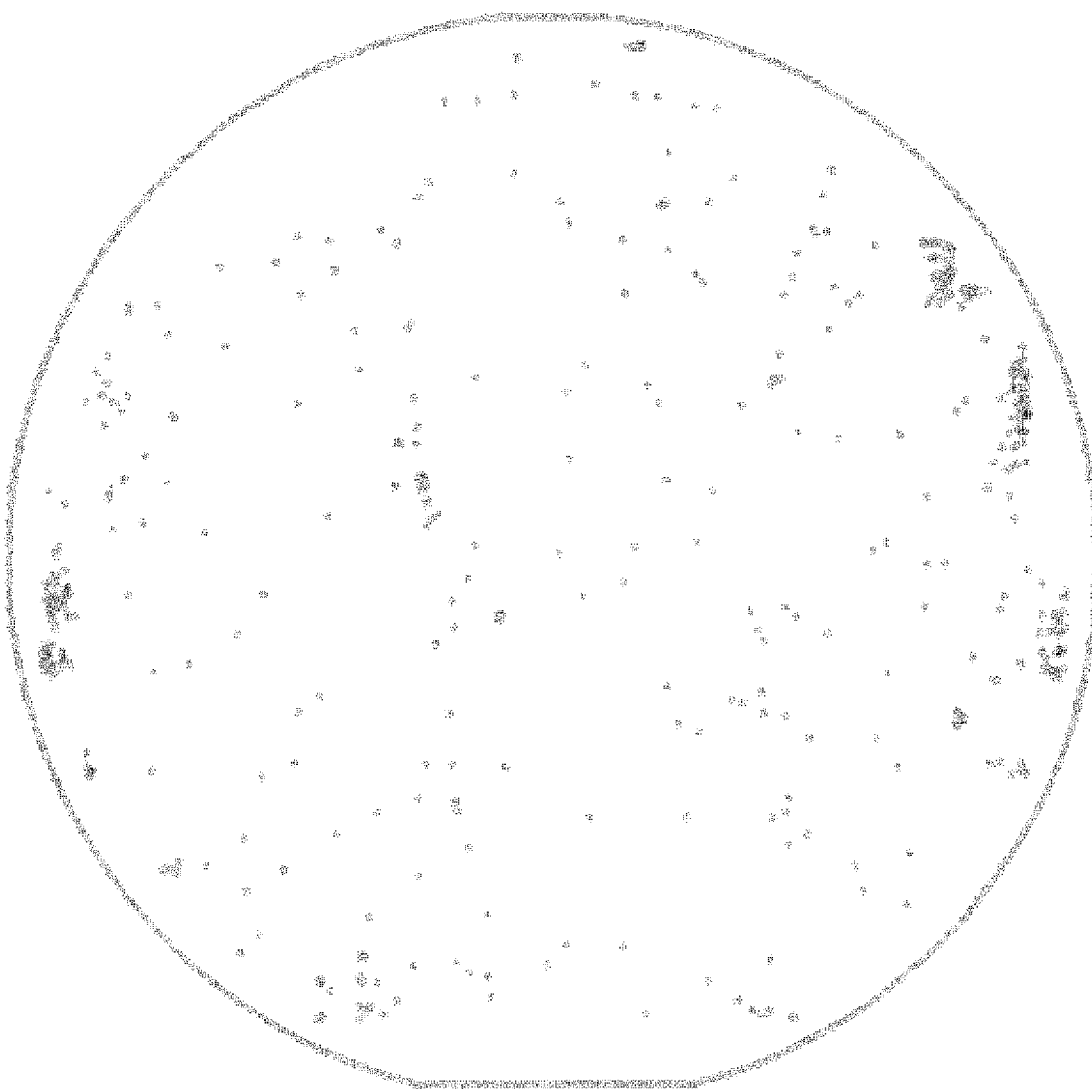


FIG. 12

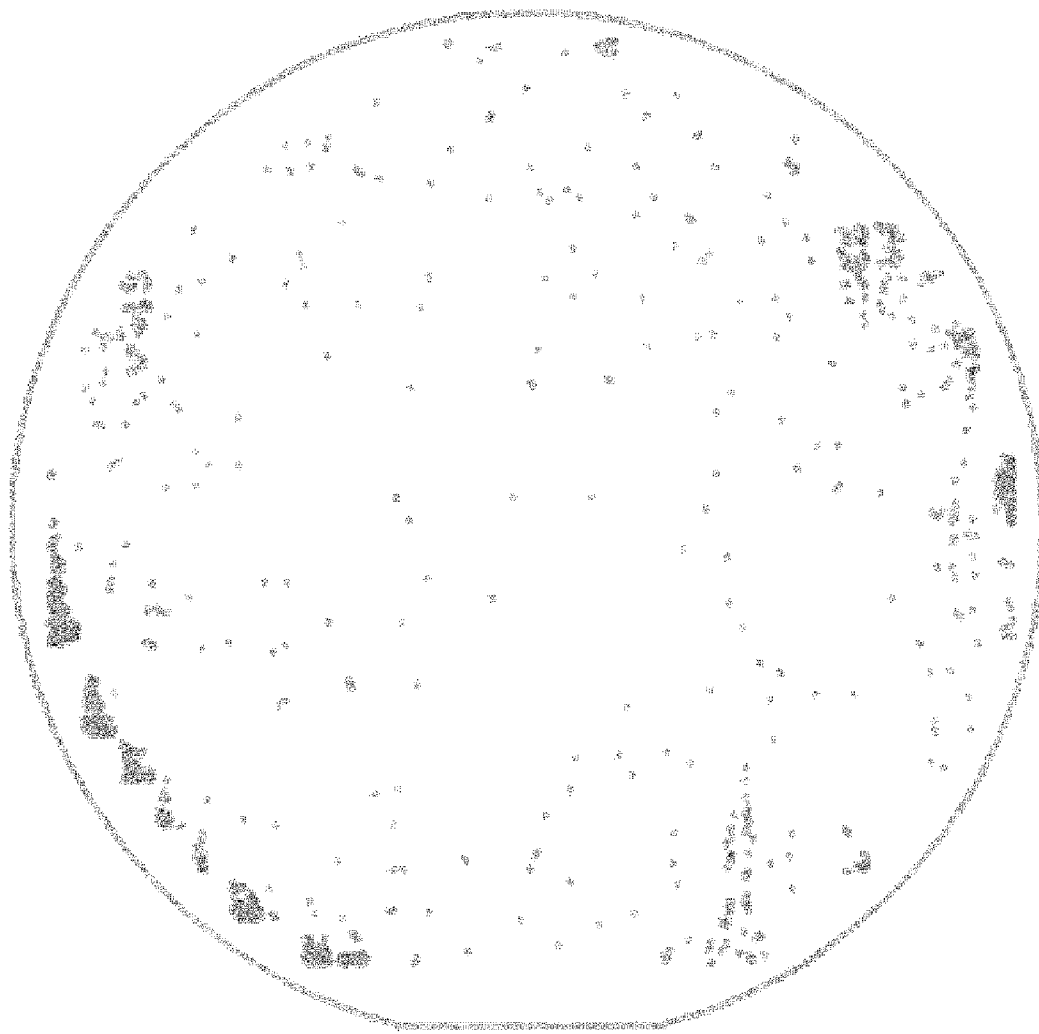
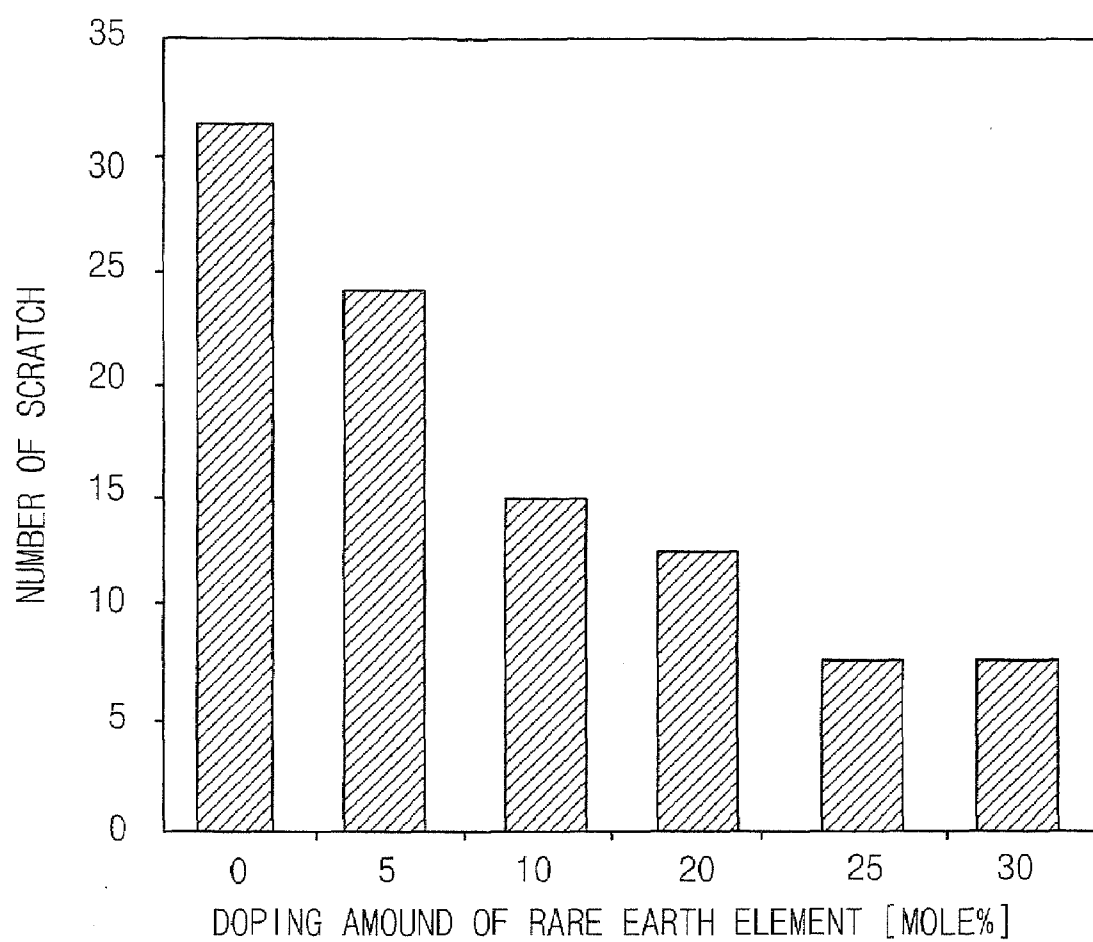


FIG. 13



METHODS OF POLISHING AN OBJECT USING SLURRY COMPOSITIONS

RELATED APPLICATION DATA

[0001] This application claims the benefit of Korean Patent Application No. 10-2008-0064217, filed on Jul. 3, 2008, in the Korean Intellectual Property Office, the disclosure of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0002] Embodiments of the present invention relate to slurry compositions, methods of preparing the slurry compositions and methods of polishing an object using the slurry compositions. More particularly, embodiments of the present invention relate to slurry compositions for chemical mechanical polishing that may be employed in manufacturing a semiconductor device.

BACKGROUND

[0003] Chemical mechanical polishing (CMP) is a technique that may be used in semiconductor fabrication for planarizing a semiconductor wafer. The CMP technique may include chemical etching of a slurry composition and a mechanical abrasion caused by an abrasive and a polishing pad. The CMP technique was developed by IBM in the late 1980s, and so far it has been widely used in global planarization for manufacturing a semiconductor chip.

[0004] In a CMP process, a surface of a substrate may be mechanically polished by rubbing the surface of the substrate with an abrasive and protrusions of a polishing pad, and further chemically polished by a chemical reaction with components contained in a slurry composition. The abrasive contained in the slurry composition may mechanically grind the substrate under a pressure provided from a polishing apparatus. Silica or silicon oxide (SiO_2), ceria or cerium oxide (CeO_2), alumina or aluminum oxide (Al_2O_3) and the like may be generally used as an abrasive.

[0005] Some commercial abrasives employ undoped or pure cerium oxide particles. A pure cerium oxide abrasive may include a crystal grain having a faceted shape and a wide distribution of the diameter of the particles. Such pure cerium oxide abrasives may frequently cause a scratch defect on a wafer, which may generate a decrease in the production yield and/or reliability deterioration of a semiconductor device.

SUMMARY

[0006] Embodiments of the present invention provide slurry compositions for CMP having improved polishing characteristics. Exemplary embodiments also provide methods of preparing the slurry compositions. Exemplary embodiments further provide methods of polishing an object using the slurry compositions.

[0007] According to some exemplary embodiments, a slurry composition for CMP includes a cerium oxide abrasive particle having a rare earth element other than cerium oxide as a dopant, and an aqueous medium for dispersing the cerium oxide abrasive particle.

[0008] In an exemplary embodiment, the rare earth element may include samarium (Sm).

[0009] In other exemplary embodiments, an amount of the rare earth element may be in a range of about 10 to about 40% by mole, based on a total mole of cerium and the rare earth

element. In further exemplary embodiments, the amount of the rare earth element may be in a range of about 20 to about 30% by mole.

[0010] In some exemplary embodiments, the cerium oxide abrasive particle may have a mean grain diameter of less than about 29 nm. The cerium oxide abrasive particle may have a mean diameter of a secondary particle in a range of about 70 nm to about 120 nm.

[0011] In some exemplary embodiments, the aqueous medium may include a dispersing agent and water. An amount of the dispersing agent may be in a range of about 0.05 to about 5% by weight, based on a total weight of the slurry composition.

[0012] In some exemplary embodiments, an amount of the cerium oxide abrasive particle may be in a range of about 1 to about 10% by weight, based on a total weight of the slurry composition.

[0013] According to other exemplary embodiments, there is provided a method of preparing a slurry composition for CMP. In the method, a cerium salt and a salt of a rare earth element other than cerium may be co-precipitated in an aqueous solution to obtain a precipitate including a rare earth element and cerium. The precipitate may be thermally treated to form a preliminary cerium oxide abrasive particle doped with the rare earth element. The preliminary cerium abrasive particle doped with the rare earth element may be grinded to form a cerium oxide abrasive particle doped with the rare earth element. The slurry composition may be obtained by dispersing the cerium oxide abrasive particle doped with the rare earth element in an aqueous medium.

[0014] In an exemplary embodiment, the precipitate may be thermally treated at a temperature of about 600° C. to about 900° C.

[0015] According to still other exemplary embodiments, there is provided a method of chemically and mechanically polishing an object. In the method, a slurry composition may be provided between an object and a polishing pad. The slurry composition may include a cerium oxide abrasive particle having a rare earth element other than cerium as a dopant, and an aqueous medium for dispersing the cerium oxide abrasive particle. A surface of the object may be polished by contacting the object with the polishing pad.

[0016] In an exemplary embodiment, the object may include a substrate having a trench and an insulation layer for device isolation on the substrate to fill the trench.

[0017] In other exemplary embodiments, the object may include a substrate on which a conductive structure is formed and an insulating interlayer on the substrate to cover the conductive structure.

[0018] According to further exemplary embodiments, the slurry composition includes a cerium abrasive particle doped with a rare earth element. The cerium oxide abrasive particle doped with a rare earth element may have a proper shape and/or size for reducing generation of a scratch defect on a surface of an object as compared with a pure cerium oxide abrasive particle. The cerium abrasive particle doped with a rare earth element may have an improved fracture strength, so generation of debris or fine particles may be reduced during a grinding process and the amount of a large or agglomerated particle dispersed in the slurry composition may also be reduced. The slurry composition may reduce generation of a defect (e.g., a scratch) on an object by employing such an

abrasive particle having a controlled shape and size of a crystal grain and a narrow distribution of a particle diameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Exemplary embodiments will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings. FIGS. 1-13 represent non-limiting, exemplary embodiments as described herein.

[0020] FIG. 1 is an electron microscopic picture showing a crystal grain of a cerium oxide abrasive particle doped with a rare earth element.

[0021] FIG. 2 is an electron microscopic picture showing a crystal grain of a pure or undoped cerium oxide abrasive particle.

[0022] FIG. 3 is a flow chart illustrating a method of preparing a slurry composition according to exemplary embodiments.

[0023] FIG. 4 is a flow chart illustrating a method of polishing an object according to exemplary embodiments.

[0024] FIG. 5 is a schematic diagram illustrating a CMP apparatus that may be employed in polishing an object according to exemplary embodiments.

[0025] FIGS. 6A to 6D are cross-sectional views illustrating a method of manufacturing a semiconductor device according to some exemplary embodiments.

[0026] FIGS. 7A to 7C are cross-sectional views illustrating a method of manufacturing a semiconductor device according to other exemplary embodiments.

[0027] FIG. 8 is a graph showing size distributions of abrasive particles contained in the slurry compositions obtained in Example 1 and Comparative Example 1.

[0028] FIGS. 9 and 10 are electron microscopic pictures showing abrasive particles included in the slurry compositions obtained in Example 1 and Comparative Example 1, respectively.

[0029] FIGS. 11 and 12 are wafer maps illustrating a distribution of scratch defects on a wafer polished using each of the slurry compositions obtained in Example 1 and Comparative Example 1.

[0030] FIG. 13 is a graph showing the number of scratches generated on a wafer according to the doping amount of the rare earth element.

DETAILED DESCRIPTION

[0031] Various exemplary embodiments will be described more fully hereinafter with reference to the accompanying drawings, in which some exemplary embodiments are shown. Exemplary embodiments may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiments set forth herein. Rather, these exemplary embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. In the drawings, the sizes and relative sizes of layers and regions may be exaggerated for clarity.

[0032] It will be understood that when an element or layer is referred to as being “on,” “connected to” or “coupled to” another element or layer, it may be directly on, connected or coupled to the other element or layer or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly connected to” or “directly coupled to” another element or layer, there are no

intervening elements or layers present. Like numerals refer to like elements throughout. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0033] It will be understood that, although the terms first, second, third etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of example embodiments.

[0034] Spatially relative terms, e.g., “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would be oriented “above” the other elements or features. Thus, the exemplary term “below” may encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0035] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0036] Exemplary embodiments are described herein with reference to cross-sectional illustrations that are schematic illustrations of idealized exemplary embodiments (and intermediate structures). As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, exemplary embodiments should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, an implanted region illustrated as a rectangle may, typically, have rounded or curved features and/or a gradient of implant concentration at its edges rather than a binary change from implanted to non-implanted region. Likewise, a buried region formed by implantation may result in some implantation in the region between the buried region and the surface through which the implantation takes place. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the actual shape of a region of a device and are not intended to limit the scope of the present invention.

[0037] Unless otherwise defined, all terms including technical and scientific terms used herein have the same meaning

as commonly understood by one of ordinary skill in the art to which example embodiments belongs. It will be further understood that terms, e.g., those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0038] Embodiments of the present invention provide slurry compositions. These compositions are particularly useful for CMP. According to exemplary embodiments, a slurry composition may include a ceria (i.e., cerium oxide) abrasive particle doped with a rare earth element, and an aqueous medium for dispersing the cerium oxide abrasive particle. The cerium oxide abrasive particle doped with a rare earth element may have a narrow size distribution and a proper shape of a crystal grain for reducing generation of a scratch defect on a surface of an object, as compared with a pure cerium oxide abrasive particle. Thus, the slurry composition may reduce generation of a defect (e.g., a scratch) on an object by employing such an abrasive particle.

[0039] In exemplary embodiments, the cerium oxide abrasive particle may be doped with a rare earth element excluding cerium. Examples of the rare earth element may include samarium (Sm), scandium (Sc), yttrium (Y), lanthanum (La), praseodymium (Pr), neodymium (Nd), promethium (Pm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and the like with the proviso that the rare earth element is not cerium. These rare earth elements may be used alone or in a combination thereof. In some exemplary embodiments, the cerium oxide abrasive particle may include samarium (Sm) as a dopant.

[0040] The amount of the rare earth element contained in the cerium oxide abrasive particle may be changed to control the shape and/or size of a crystal grain, the polishing rate, and the amount of large or agglomerated particles dispersed in an aqueous medium, etc. In some exemplary embodiments, the amount of the rare earth element may exceed about 5% by mole, based on a total mole of cerium and the rare earth element. In other exemplary embodiments, the amount of the rare earth element may be greater than or equal to about 10% by mole. In still other exemplary embodiments, the amount of the rare earth element may be in a range of about 10–40% by mole, or in a range of about 20–30% by mole.

[0041] In exemplary embodiments, the cerium oxide abrasive particle doped with the rare earth element may primarily have a sphere-like crystal grain (i.e., a primary particle).

[0042] FIG. 1 is an electron microscopic picture showing a crystal grain of a cerium oxide abrasive particle doped with a rare earth element, and FIG. 2 is an electron microscopic picture showing a crystal grain of a pure or undoped cerium oxide abrasive particle.

[0043] As shown in FIGS. 1 and 2, the pure or undoped cerium oxide abrasive particle may have a faceted crystal grain as having a clear [111] crystal face, because pure cerium oxide may have a tendency to grow into a cube. However, the cerium oxide abrasive particle doped with a rare earth element may have a sphere-like crystal grain, because crystal faces and [100] may grow uniformly in cerium oxide doped with a rare earth element.

[0044] During crystal growth of cerium oxide, the rare earth element may act to encapsulate a crystal growing face and may further inhibit the growth of a specific crystal face. The sphere-like crystal grain may reduce generation of

scratches on a surface of an object to be polished, as compared with a faceted crystal grain. While a cerium abrasive particle is prepared by grinding, the sphere-like crystal grain may also suppress formation of fine or ultra-fine particles smaller than a particle having an average diameter.

[0045] In exemplary embodiments, the cerium abrasive particle doped with a rare earth element may have a mean diameter of a crystal grain smaller than that of a pure cerium oxide abrasive particle even though these cerium oxide abrasive particles are formed under substantially the same conditions. The rare earth element may inhibit growing of a cerium oxide crystal on a growing surface, so the size of a crystal grain may become smaller. In some exemplary embodiments, the cerium abrasive particle doped with the rare earth element may include a crystal grain having a mean diameter smaller than about 29 nm. In other exemplary embodiments, the mean diameter of a crystal grain may be in a range of about 25 nm to about 27 nm. The size of the crystal grain of the cerium oxide abrasive particle may be determined using an electron microscope, or using an X-ray diffraction analysis and the Scherrer's equation as shown below as Equation 1.

$$d = 0.9\lambda / (\beta \cos \theta) \quad [\text{Equation 1}]$$

[0046] In Equation 1, “d” denotes a diameter of a crystal grain, “λ” denotes a wavelength of X-ray, “β” denotes a full width at half maximum in a peak, and “θ” denotes a diffraction angle of the peak.

[0047] In exemplary embodiments, the cerium oxide abrasive particle doped with the rare earth element may be a secondary particle including at least one crystal grain (i.e., a primary particle). The mean diameter of the secondary particle may be changed to improve dispersibility, the polishing rate, the number of scratches, etc. For example, the mean diameter of the secondary particle may be in a range of about 50 nm to about 200 nm. In other embodiments, the mean diameter of the secondary particle may be in a range of about 70 nm to about 120 nm.

[0048] In further exemplary embodiments, the cerium oxide abrasive particle doped with the rare earth element may reduce the amount of large or agglomerated particles dispersed in the slurry composition, as compared with using pure cerium oxide abrasive particles. For example, the rare earth element (e.g., Sm) may enhance a fracture strength of a cerium oxide abrasive particle. When the fracture strength increases, generation of fine or ultra-fine particles or debris may be suppressed during a grinding process, and the size distribution of particles may become smaller. Such fine or ultra-fine particles may be readily agglomerated in an aqueous medium to form large or agglomerated particles in the slurry compositions. In some exemplary embodiments, the rare earth element doped in the cerium oxide abrasive particle may inhibit formation of fine particles or debris, so the amount of large particles which may cause scratches on a surface of an object to be polished may be reduced in the slurry composition.

[0049] In some embodiments, the amount of large particles greater than about 2 μm dispersed in the slurry composition may be less than about 160 ppm, based on a total weight of the slurry composition. In other exemplary embodiments, the amount of large particles greater than about 2 μm may be less than about 110 ppm, less than about 65 ppm, or less than about 30 ppm.

[0050] The amount of the cerium oxide abrasive particle doped with the rare earth element included in the slurry com-

position may be changed to improve dispersibility, the polishing rate, the polishing selectivity, etc. For example, the amount of the abrasive particle may be in a range of about 1 to about 10% by weight. In other exemplary embodiments, the amount of the abrasive particle may be from about 2 to about 7% by weight.

[0051] The slurry composition may include an aqueous medium for dispersing the cerium oxide abrasive particle doped with the rare earth element. The aqueous medium may include water and a dispersing agent. The dispersing agent may be a compound capable of dispersing the cerium oxide abrasive particle. Non-limiting examples of the dispersing agent may include poly(acrylic acid), poly(acrylic acid, ammonium salt), poly(acrylic acid, amine salt) and the like.

[0052] The amount of the dispersing agent may be changed to improve dispersibility and stability of the slurry composition. For example, the amount of the dispersing agent may be in a range of about 0.05 to about 5% by weight. In other embodiments, the amount of the dispersing agent may be in a range of about 0.1 to about 1% by weight.

[0053] In further exemplary embodiments, the slurry composition may optionally include a pH-controlling agent, an additive for improving polishing selectivity, a surfactant or combinations thereof.

[0054] In exemplary embodiments, the slurry composition may include a pH-controlling agent to improve the polishing rate or polishing selectivity. Examples of an acid pH-controlling agent may include an inorganic acid (e.g., sulfuric acid, hydrochloric acid, nitric acid, phosphoric acid, etc.) and an organic acid (e.g., acetic acid, citric acid, etc.) Examples of a basic pH-controlling agent may include sodium hydroxide, potassium hydroxide, ammonium hydroxide, quaternary organic ammonium hydroxide, etc. The amount of the pH-controlling agent may be properly changed to consider a final pH.

[0055] In some exemplary embodiments, the slurry composition may include an additive for improving polishing selectivity. When at least two different materials are exposed in a polishing process, the additive may function to selectively remove a specific material relative to other materials. For example, the additive disclosed in Korean Patent No. 475,457 assigned to Samsung Electronics may be included in the slurry composition. The additive disclosed in the patent is a composition including two types of poly(acrylic acid) having different weight-average molecular weights from each other. The additive may be employed in selectively polishing silicon oxide relative to silicon nitride. For example, the additive may be used in an amount of about 0.1 to about 30% by weight, based on a total weight of the slurry composition. The additive may have a pH of about 3 to about 8, or a pH of about 4 to about 7.

[0056] In other embodiments, the slurry composition may include a surfactant. Cationic surfactants, anionic surfactants, non-ionic surfactant or combinations thereof may be used. Examples of the cationic surfactant may include cetyltrimethyl ammonium bromide, hexadecyltrimethyl ammonium bromide, cetylpyridinium chloride, etc. Examples of the anionic surfactant may include sodium dodecyl sulfate, ammonium lauryl sulfate, fatty acid salt, etc. Examples of the non-ionic surfactant may include alkyl poly(ethylene oxide), alkyl poly(propylene oxide), a copolymer of poly(ethylene oxide) and poly(propylene oxide), etc. The amount of the surfactant may be in a range of about 0.001 to about 10% by weight.

[0057] Embodiments of the present invention further include methods of preparing a slurry composition for CMP. FIG. 3 is a flow chart illustrating a method of preparing a slurry composition according to an exemplary embodiment.

[0058] Referring to FIG. 3, a precipitate may be prepared by co-precipitating a salt of a rare earth element and a cerium salt in an aqueous solution (S110).

[0059] The salt of a rare earth element and the cerium salt may be dissolved in an aqueous solution (e.g. water) to produce a rare earth metal ion and a cerium ion, respectively. Examples of the rare earth element, with the exception of cerium, may include samarium (Sm), scandium (Sc), yttrium (Y), lanthanum (La), praseodymium (Pr), neodymium (Nd), promethium (Pm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and the like. These rare earth elements may be used alone or in a combination thereof. Examples of the rare earth element salt may include a nitrate, a sulfate, a carbonate, a halogenide, a perchlorate, an acetate, an acetyl acetonate, an oxalate or a 2-ethylhexanoate of the rare earth metal. For example, samarium nitrate, samarium sulfate, samarium carbonate, samarium acetate, gadolinium nitrate, praseodymium carbonate, etc. may be used. These rare earth element salts may be used alone or in a combination thereof.

[0060] Examples of the cerium salt may include cerium nitrate, cerium sulfate, cerium carbonate, cerium halide, cerium perchlorate, cerium acetate, cerium acetyl acetonate, cerium oxalate, cerium 2-ethyl hexanoate, etc. These cerium salts may be used alone or in a combination thereof.

[0061] The precipitate obtained by co-precipitation of the rare earth metal salt and the cerium salt may be homogeneous. For example, the precipitate may be a nitrate, a carbonate, a sulfate, an acetate, an oxalate or a hydroxide of cerium-rare earth metal. In exemplary embodiments, a carbonate of cerium-rare earth element may be obtained by co-precipitating an aqueous solution including a cerium salt and a rare earth metal salt with a precipitator (e.g., an inorganic carbonate, urea, etc.). Examples of the precipitator may include ammonium carbonate ((NH₄)₂CO₃), ammonium hydrogen carbonate ((NH₄)HCO₃), urea, etc.

[0062] The amounts of the cerium salt and the rare earth metal salt may be changed to control the shape and/or a size of a crystal grain, the polishing rate, and the amount of large or agglomerated particles dispersed in an aqueous medium, etc. In some exemplary embodiments, the amount of the rare earth element salt may exceed about 5% by mole, based on a total mole of the cerium salt and the rare earth element salt. In other embodiments, the amount of the rare earth element salt may be greater than or equal to about 10% by mole. In still other exemplary embodiments, the amount of the rare earth element salt may be in a range of about 10~40% by mole, or in a range of about 20~30% by mole.

[0063] The aqueous solution used in preparing the precipitate may include water, and may optionally include a pH-controlling agent. Examples of the pH-controlling agent may include an inorganic acid (e.g., sulfuric acid, hydrochloric acid, nitric acid, etc.), an organic acid (e.g., acetic acid, citric acid, etc.), or a basic compound (e.g., ammonium hydroxide, sodium hydroxide, potassium hydroxide, organic ammonium hydroxide, etc.). The pH of the aqueous solution for precipitation may be adjusted in a range of about 4 to about 13. The aqueous solution for precipitation may optionally include a nucleation seed, a dispersing agent, etc.

[0064] The precipitate may be prepared by stirring the aqueous solution, in which the cerium salt and the rare earth metal salt are dissolved, at a temperature of about 40~80° C. The reaction time may be properly adjusted to consider a temperature of the aqueous solution, concentrations of reactants, types of additives, etc.

[0065] Referring to FIG. 3, a preliminary cerium oxide abrasive particle doped with a rare earth element may be formed by thermally treating the precipitate (S120). Cerium oxide powder doped with a rare earth element may be obtained by thermally treating the precipitate.

[0066] The thermal treatment may be performed under an air or oxygen atmosphere to form an oxide. The time of the thermal treatment may be adjusted to consider the size of grain or particle. For example, the thermal treatment may be carried out for a period of time in a range from about ten minutes to about six hours.

[0067] The temperature of the thermal treatment may be changed to consider the grain size, crystal growth rate, etc. For example, the thermal treatment may be performed at a temperature of about 500° C. to about 950° C. In other exemplary embodiments, the thermal treatment may be performed at a temperature of about 600° C. to about 900° C., or about 600° C. to about 750° C.

[0068] Referring to FIG. 3, a cerium oxide abrasive particle doped with a rare earth element may be formed by grinding the preliminary cerium oxide abrasive particle doped with a rare earth element to control a particle size and a size distribution (S130). The grinding process may be performed by a jet milling, a disc milling, a bead milling, etc. Large or coarse particles may be pulverized while performing the grinding process, so a size distribution of the secondary particles may become smaller within a specific range. As a result, a cerium oxide abrasive particle doped with a rare earth element may be obtained to have a uniform size.

[0069] In further exemplary embodiments, the cerium oxide abrasive particle doped with the rare earth element may have a mean diameter of a particle (i.e., a secondary particle) in a range of about 50 nm to about 200 nm. In other embodiments, the abrasive particle may have a mean diameter of about 70 nm to about 120 nm.

[0070] The cerium oxide abrasive particle doped with the rare earth element may have an improved fracture strength, as compared with a pure cerium oxide abrasive particle. Pure cerium oxide particles may have a relatively low fracture strength. Thus, the pure cerium oxide particles may be easy to break and a generation of fine or ultra-fine particles or debris much smaller than an average-sized particle may increase in the grinding process. Such fine or ultra-fine particles may be readily agglomerated in an aqueous medium to form large or agglomerated particles in the slurry compositions. However, the cerium oxide abrasive particle doped with the rare earth element may have a relatively high fracture strength, so a generation of fine particles or debris may be reduced or suppressed and the amount of large or agglomerated particles in the slurry composition may be greatly reduced.

[0071] Referring to FIG. 3, a slurry composition for CMP may be prepared by dispersing the cerium oxide abrasive particle doped with the rare earth element in an aqueous medium (S140). The aqueous medium may include a dispersing agent and water. The dispersing process may be performed using a stirrer or a disperser. In some embodiments, the slurry composition may optionally include a pH-control-

ling agent, an additive for improving polishing selectivity, a surfactant or combinations thereof.

[0072] According to exemplary embodiments, the slurry composition may include the cerium oxide abrasive particle doped with the rare earth element. The cerium oxide abrasive particle doped with the rare earth element may be prepared by doping the rare earth element into cerium oxide to have a sphere-like shape and a relatively smaller grain size as compared with a pure cerium oxide particle. The cerium oxide abrasive particle doped with the rare earth element may have an improved fracture strength such that generation of fine particles may be suppressed during the grinding process and the amount of a large or agglomerated particle dispersed in the slurry composition may also be reduced. As a result, an abrasive particle having a narrow size distribution may be obtained.

[0073] Embodiments of the present invention further include methods of chemically and mechanically polishing an object. FIG. 4 is a flow chart illustrating a method of polishing an object according to exemplary embodiments. FIG. 5 is a schematic diagram illustrating a CMP apparatus that may be employed in polishing an object according to further exemplary embodiments.

[0074] Referring to FIG. 4, a slurry composition including a cerium oxide abrasive particle doped with a rare earth element and an aqueous medium may be prepared (S210). The slurry composition may be prepared by the method described with reference to FIG. 3.

[0075] Referring to FIGS. 4 and 5, a slurry composition 165 may be provided between an object 100 to be polished and a polishing pad 156 (S220). In some embodiments, a CMP apparatus may include a rotational table 150 on which the polishing pad 156 may be located, a rotational axis 153, a carrier 159 for holding the object 100, and a conditioning pad 162 for improving a surface of the polishing pad 156.

[0076] The carrier 159 may be arranged over a portion of the rotational table 150, and the conditioning pad 162 may be arranged over a remaining portion of the rotational table 150. The object 100 to be polished may be mounted on the carrier 159 such that a polishing surface of the object 100 may face the polishing pad 156 downwards. The object 100 located on the carrier 159 may be arranged to make contact with the polishing pad 156 on the rotational table 150. The carrier 159 holding the object 100 may rotate in the same direction as that of the rotational axis 153. Rotational speeds of the carrier 159 and the rotational axis 153 may be different from each other.

[0077] The slurry composition 165 may be provided from a providing nozzle (not illustrated) located over the rotational table 150 toward a center portion of the polishing pad 156. The slurry composition 165 dropped on the polishing pad 156 may move toward an edge portion of the polishing pad 156 due to the centrifugal force. Accordingly, the slurry composition 165 may be provided between the polishing pad 156 and the object 100.

[0078] The object 100 may be a semiconductor substrate, or a semiconductor substrate on which various structures (e.g., a layer, a film, a wiring, a pad, a plug, a gate, a capacitor, etc.) may be formed. In exemplary embodiments, the object 100 may be a substrate on which an insulation layer (e.g., an oxide layer, a nitride layer, an oxynitride layer, a low-dielectric (k) layer or a high-k layer) may be formed. In other embodiments, the object 100 may be a substrate on which a metal layer (e.g., a tungsten layer, a copper layer, an aluminum layer, etc.) may be formed.

[0079] In further exemplary embodiments, the object 100 may be a substrate on which an insulation layer for forming an isolation layer may be formed. For example, the insulation layer for forming an isolation layer may be formed on a substrate to fill a trench formed at the substrate. The insulation layer may be formed using silicon oxide, silicon oxynitride, silicon nitride, etc.

[0080] In some embodiments, the object 100 may be a substrate on which an insulating interlayer may be formed. For example, the insulating interlayer may be formed on the substrate having a conductive structure (e.g., a conductive line, a conductive pad, etc.) to cover the conductive structure. The insulating interlayer may be formed using silicon oxide, silicon oxynitride, silicon nitride, etc.

[0081] The surface of the object 100 may be polished by contacting the object 100 with the polishing pad 156 (S230). Contacting the object 100 with the polishing pad 156 may be performed while a down pressure (I) is applied to the object from the carrier 159 and rotations (II, III) of the polishing pad 156 and the carrier 159 is adjusted. The surface of the object 100 may be mechanically rubbed by the abrasive particle and protrusions of the polishing pad 156. Simultaneously, the surface of the object 100 may be reacted with chemical components of the slurry composition to remove or etch the object 100.

[0082] According to exemplary embodiments, the slurry composition 165 includes the cerium oxide abrasive particle doped with the rare earth element and the aqueous medium. The cerium oxide abrasive particle doped with the rare earth element may have proper shape and/or size for reducing a generation of a scratch defect on a surface of an object as compared with a pure cerium oxide abrasive particle. The cerium oxide abrasive particle doped with the rare earth element may also have an improved fracture strength so that generation of debris or fine particles may be reduced during a grinding process and the amount of a large or agglomerated particle dispersed in the slurry composition may also be reduced. The slurry composition 165 may reduce generation of a defect (e.g., a scratch) on the object 100 by employing such an abrasive particle having a controlled shape and size of a crystal grain and a narrow distribution of a particle diameter.

[0083] Embodiments of the present invention include methods of manufacturing a semiconductor device. FIGS. 6A to 6D are cross-sectional views illustrating a method of manufacturing a semiconductor device according to some exemplary embodiments.

[0084] Referring to FIG. 6A, a pad oxide layer 205 and a pad nitride layer 210 may be sequentially formed on a substrate 200. For example, the substrate 200 may be a semiconductor substrate such as a silicon wafer, a silicon-germanium substrate, an SOI substrate, etc. The pad oxide layer 205 may be formed on the substrate 200 to reduce a stress between the substrate 200 and the pad nitride layer 210. In some embodiments, the pad oxide layer 205 may be formed by performing a thermal oxidation or a chemical vapor deposition (CVD).

[0085] The pad nitride layer 210 may be formed on the substrate 200 on which the pad oxide layer 210 is formed. The pad nitride layer 210 may be used as a mask for forming a trench 220 (see FIG. 6B) in the substrate 200. In some embodiments, the pad nitride layer 210 may be formed by performing a low pressure CVD or a plasma-enhanced CVD using an SiH_2Cl_2 gas, an SiH_4 gas, an NH_3 gas, etc.

[0086] A photoresist pattern 215 may be formed on the pad nitride layer 210. The photoresist pattern 215 may be used as

a mask for patterning the pad nitride layer 210 and the pad oxide layer 205. In exemplary embodiments, the photoresist pattern 215 may be formed by coating the pad nitride layer 210 with a photoresist composition and by performing an exposure process and a developing process on a photoresist film.

[0087] Referring to FIG. 6B, the pad nitride layer 210 and the pad oxide layer 205 may be partially etched using the photoresist pattern 215 as an etching mask to form a pad nitride layer pattern 210a and the pad oxide layer pattern 205a. The pad nitride layer pattern 210a and the pad oxide layer pattern 205a may be a mask pattern for forming the trench 220 in the substrate 200. In exemplary embodiments, the photoresist pattern 215 may be removed from the substrate 200 by an ashing process and/or a stripping process after forming the pad nitride layer pattern 210a and the pad oxide layer pattern 205a on the substrate 200.

[0088] The trench 220 may be formed by etching a portion of the substrate 200 exposed by the pad nitride layer pattern 210a and the pad oxide layer pattern 205a. The trench may define an active region and a field region. The trench 220 may have an inclined sidewall relative to a vertical direction of the substrate 200. For example, the trench 220 may be formed by an anisotropic etching process.

[0089] In exemplary embodiments, a liner layer (not illustrated) may be optionally formed on a bottom and a sidewall of the trench 220. The liner layer may be formed to cure damage generated on an exposed surface of the substrate 200 and to suppress occurrence of a leakage current. For example, the liner layer may be formed by thermally oxidizing the surface of the substrate 200 exposed by the trench 220, or by depositing an insulation material (e.g., silicon nitride).

[0090] Referring to FIG. 6C, an insulation layer 225 may be formed on the substrate 220 using an insulation material. The insulation layer 225 may be formed on the pad nitride layer 210a to fill the trench 220.

[0091] In some embodiments, the insulation layer 225 may be formed by a silicon oxide. Examples of silicon oxides may include tetraethyl orthosilicate (TEOS), plasma-enhanced TEOS (PE-TEOS), O_3 -TEOS, borophosphosilicate glass (BPSG), phosphosilicate glass (PSG), undoped silicate glass (USG), spin-on glass (SOG), high density plasma CVD oxide, and the like.

[0092] Referring to FIG. 6D, a polishing process may be performed using a slurry composition for CMP on the substrate 200 on which the insulation layer 225 may be formed. The polishing process may be performed until an upper face of the pad nitride layer pattern 225 is exposed to form an insulation layer pattern 225a in the trench 220.

[0093] During the polishing process, the slurry composition according to exemplary embodiments may be applied. The slurry composition may include a cerium oxide abrasive particle doped with a rare earth element and an aqueous medium. The cerium oxide abrasive particle doped with the rare earth element may have a proper shape and/or size for reducing generation of a scratch defect on a surface of an object as compared with a pure cerium oxide abrasive particle. The cerium oxide abrasive particle doped with the rare earth element may also have an improved fracture strength so that generation of debris or fine particles may be reduced during a grinding process and an amount of a large or agglomerated particle dispersed in the slurry composition may also be reduced. The slurry composition may reduce generation of a defect (e.g., a scratch) on the insulation layer pattern 225a

by employing such an abrasive particle having a controlled shape and size of a crystal grain and a narrow distribution of a particle diameter.

[0094] When the insulation layer **225** is formed using silicon oxide, the pad nitride layer pattern **210a** may be provided as a polishing stop layer. In this case, the slurry composition may include an additive for improving polishing selectivity. The additive disclosed in Korean Patent No. 475,457 may be added to the slurry composition.

[0095] The insulation layer pattern **225** may be formed by a polishing process using the cerium oxide abrasive particle doped with a rare earth element to reduce defects of a device. Although not illustrated in the drawings, the pad nitride layer pattern **210a** and the pad oxide layer pattern **205a** may be sequentially removed from the substrate **200** after forming the insulation layer pattern **225** in the trench **220**. A tunnel oxide layer, a floating gate, a dielectric layer and a control gate may be sequentially formed on exposed portions of the substrate **200**. Accordingly, a non-volatile memory device (e.g., a flash memory) may be manufactured on the substrate **200**.

[0096] FIGS. 7A to 7C are cross-sectional views illustrating a method of manufacturing a semiconductor device according to other exemplary embodiments.

[0097] Referring to FIG. 7A, a conductive structure **315** may be formed on a substrate **300** to have a conductive layer pattern **305** and a mask layer pattern **310**. The conductive structure **315** may be a conductive line, a wiring, a gate, etc. For example, the substrate **200** may be a semiconductor substrate such as a silicon wafer, a silicon-germanium substrate, an SOI substrate, etc. The substrate **300** may include other lower structures (not illustrated). The lower structures may include a contact region, a pad, a plug, a conductive wiring, a conductive pattern, an insulation layer, etc.

[0098] In some embodiments, the conductive layer pattern **305** may be formed on the substrate **300** to be electrically connected to the lower structure having conductivity. In other embodiments, an insulation layer may be optionally formed between the conductive layer pattern **305** and the substrate **300**. The insulation layer may be provided as a gate insulation layer, a tunnel oxide layer, etc.

[0099] In exemplary embodiments, a conductive layer and a mask layer may be sequentially formed on the substrate **300**. A photoresist pattern (not illustrated) may be formed on the mask layer, and then the conductive layer and the mask layer may be sequentially patterned using the photoresist pattern as an etching mask to form the conductive layer pattern **305** and the mask layer pattern **310**.

[0100] The conductive layer may be formed using, for example, doped polysilicon, tungsten (W), aluminum (Al), copper (Cu), titanium (Ti), tungsten nitride (WN_x), aluminum nitride (AlN_x), titanium nitride (TiN_x), titanium aluminum nitride (TiAl_xN_y) and the like. The conductive layer may be formed by a sputtering, CVD, an atomic layer deposition (ALD) or a pulse laser deposition process. The mask layer may be formed using, for example, silicon nitride, silicon oxynitride, metal nitride, etc.

[0101] Referring to FIG. 7B, a preliminary insulating interlayer **320** may be formed on the substrate **300** on which the conductive structure **315** may be formed. The preliminary insulating interlayer **320** may be formed to cover the conductive structure **315**. In example embodiments, the preliminary insulating interlayer **320** may be formed using a silicon oxide. Examples of silicon oxide may include TEOS, PE-TEOS, O₃-TEOS, BPSG, PSG, USG, SOG, HDP-CVD oxide, etc.

For example, the preliminary insulating interlayer **320** may be formed by a CVD, a PE-CVD, an ALD or a HDP-CVD.

[0102] Referring to FIG. 7C, a polishing process may be performed on the preliminary insulating interlayer **320** using a slurry composition for CMP to form an insulating interlayer **320a**. In exemplary embodiments, the polishing process may be performed until an upper face of the conductive structure **315** is exposed. In this case, the mask layer pattern **310** may act as a polishing stop layer. In other embodiments, the polishing process may be performed such that the conductive structure may not be exposed.

[0103] The polishing process may be performed using the slurry composition according to exemplary embodiments. The slurry composition may include a cerium oxide abrasive particle doped with a rare earth element and an aqueous medium. The slurry composition may reduce generation of a defect (e.g., a scratch) on the insulating interlayer **320a** by employing such an abrasive particle having a controlled shape and size of a crystal grain and a narrow distribution of a particle diameter.

[0104] Exemplary embodiments of the present invention will be further described hereinafter with reference to Synthetic Examples, Examples and Comparative Examples regarding preparation of slurry compositions. These examples are illustrative of embodiments of the present invention and are not intended to be limiting of the present invention.

Preparation of a Cerium Oxide Abrasive Particle Doped with a Rare Earth Element

Synthetic Example 1

[0105] A cerium oxide abrasive particle doped with samarium (Sm) was prepared. A homogeneous precipitate of samarium-cerium carbonate (Ce_{0.7}Sm_{0.3}(CO₃)₃) was prepared by co-precipitating cerium nitrate (Ce(NO₃)₃·6H₂O) and samarium nitrate (Sm(NO₃)₃·2H₂O) in an aqueous solution. After dissolving polyethylene glycol having a weight-average molecular weight of about 600 in water, cerium nitrate and samarium nitrate were dissolved in the aqueous solution with a molar ratio of about 70% (Ce) and about 30% (Sm). A nucleation seed was also added to the aqueous solution. An excess amount of ammonium hydrogen carbonate (NH₄HCO₃) as a precipitator was added to the aqueous solution, and then the mixture was stirred at a temperature of about 70° C. with a speed of about 80 rpm until the amount of a precipitate did not further increase. The stirring time for precipitation was about 12 hours, and then the mixture was stabilized for an additional 12 hours. The reaction was carried out under a pH of about 5.5.

[0106] The samarium cerium carbonate precipitate was thermally treated at a temperature of about 650° C. to form a powder of samarium cerium oxide. The thermal treatment was performed under air for about 6 hours. The samarium cerium oxide powder was grinded by milling to form a cerium oxide abrasive particle doped with samarium having a controlled size distribution. The grinding was performed using a horizontal milling machine and a zirconium bead such that the Sm-doped cerium oxide abrasive particle had a mean diameter of about 120 nm.

[0107] A grain shape of the obtained Sm-doped cerium oxide abrasive particle was determined by observing the particle using an electron microscope. A mean diameter of the crystal grain (i.e., a primary particle) of the obtained Sm-doped cerium oxide abrasive particle was determined by an

X-ray diffraction analysis and Scherrer's equation. The analysis results are shown in Table 1 below.

Synthetic Examples 2 through 5 and Comparative Synthetic Example 1

[0108] Abrasive particles were prepared by the method substantially the same as the method of Synthetic Example 1 except that the amount of samarium nitrate and cerium nitrate were changed. Shapes and sizes of crystal grains were analyzed, and the results are shown in Table 1.

Synthetic Example 6

[0109] Sm-doped cerium oxide abrasive particles were prepared by the method substantially the same as the method of Synthetic Example 1 except that samarium nitrate and cerium nitrate were used with a molar ratio of about 25% (Sm) and about 75% (Ce), and the grinding process was performed such that a mean diameter of the abrasive particle was about 105 nm.

TABLE 1

	Sm [mol %]	Ce [mol %]	Grain Size [nm]	Grain Shape
Synthetic Example 1	30	70	26.5	spherical
Synthetic Examples 2, 6	25	75	27	spherical
Synthetic Example 3	20	80	27	spherical
Synthetic Example 4	10	90	27	semi-spherical
Synthetic Example 5	5	95	29	faceted
Comparative Synthetic Example 1	0	100	32	faceted

[0110] As shown in Table 1, it was observed that the pure cerium oxide particle prepared in Comparative Synthetic Example 1 had a faceted crystal grain. However, it was confirmed that cerium oxide particles doped with samarium of at least 10 mol % had a spherical or semispherical crystal grain. Additionally, the pure cerium oxide particle prepared in Comparative Synthetic Example 1 had a grain size of about 32 nm. Sm-doped cerium oxide particles prepared in Synthetic Examples 1-4 had a grain size of 27 nm or less, as being smaller than the grain size of the pure cerium oxide particle. Accordingly, it may be noted that doping of the rare earth element may form a sphere-like grain and reduce the size of a crystal grain.

[0111] Such a sphere-like shape and a size decrease of a crystal grain may be caused by crystal growth inhibition of the rare earth element acting as a solid solute. The rare earth element may prevent cerium oxide from growing into a cubic shape. As shown in FIG. 1, pure or undoped cerium oxide may have a tendency to grow with a faceted shape to have a crystal face. As shown in FIG. 2, however, the rare earth element may cause a uniform growth of crystal faces [111] and [100] in cerium oxide, and thus, a sphere-like crystal grain may be obtained.

Preparation of Slurry Compositions for Chemical Mechanical Polishing

Example 1

[0112] A slurry composition was prepared using the Sm-doped cerium oxide abrasive particles prepared in Synthetic Example 6. The abrasive composition was obtained by dispersing the Sm-doped cerium oxide abrasive particles in an aqueous

medium including water and poly(acrylic acid). About 5% by weight of the abrasive particle, about 1% by weight of poly(acrylic acid) and about 94% by weight of water were used, based on a total weight of the abrasive composition. The additive composition disclosed in Korean Patent No. 475,457 assigned to Samsung Electronics was prepared to improve a polishing selectivity. The additive composition having a pH of about 6.5 was prepared. The abrasive composition, the additive composition for improving a polishing selectivity and water were mixed together with a volume ratio of about 1:3:3. A slurry composition was prepared by filtrating the mixture using a 10 μ m filter supplied by Pall Corp.

Comparative Example 1

[0113] A slurry composition was prepared by the method substantially the same as the method of Example 1 except that a commercial abrasive composition including pure cerium oxide abrasive particles was used instead of the abrasive composition. A commercial cerium oxide abrasive composition (HS8005-A) provided by Hitach in Japan was used as a pure cerium oxide abrasive composition.

Example 2

[0114] A slurry composition was prepared using the Sm-doped ceria abrasive particle prepared in Synthetic Example 1. About 5% by weight of the abrasive particle, about 1% by weight of poly(acrylic acid) and about 94% by weight of water were used, based on a total weight of the slurry composition, and then the mixture was filtrated by a 10 μ m filter supplied by Pall Corp.

Examples 3 through 6 and Comparative Example 2

[0115] Slurry compositions were prepared by the method substantially the same as the method of Example 2 except that the abrasive particles prepared in Synthetic Examples 2-5 and Comparative Synthetic Example 1 were used as abrasive particles.

Evaluation of a Distribution of a Particle Diameter

[0116] Sizes of the primary particle (i.e., grain) and a secondary particle, size distributions and amounts of large agglomerated particles dispersed in the slurry compositions were analyzed. The particle size was measured using an electron microscope, and the amount of large particles larger than about 2 μ m were measured by a quantitative filtration method (QFM). The results are shown in Table 2 below and FIGS. 8 through 10.

TABLE 2

	Example 1	Comparative Example 1
Abrasive Particle	Sm-doped Ceria	Commercial Undoped Ceria
Primary Particle (grain) [nm]	27	30.5
Secondary Particle [nm]	105	124
Large Particle [$>2 \mu$ m, ppm]	15	103

[0117] Referring to Table 2, it was observed that the commercial undoped cerium oxide abrasive had a grain size of about 30.5 nm and a secondary particle diameter of about 124 nm, and produced large particles greater than about 2 μ m in the slurry composition with an amount of about 103 ppm. However, it was observed that the Sm-doped cerium oxide

abrasive had a grain size of about 27 nm and a secondary particle diameter of about 105 nm, and produced large particles greater than about 2 μm in the slurry composition with an amount of about 15 ppm. Accordingly, it may be noted that the Sm-doped cerium oxide abrasive particle may have primary and secondary particles that are smaller than those of undoped cerium oxide abrasive particles, and Sm-doped cerium oxide abrasive particles may greatly reduce the amount of large particles greater than about 2 μm in the slurry composition.

[0118] FIG. 8 is a graph showing size distributions of abrasive particles contained in the slurry compositions obtained in Example 1 and Comparative Example 1. FIGS. 9 and 10 are electron microscopic pictures showing abrasive particles included in the slurry compositions obtained in Example 1 and Comparative Example 1, respectively.

[0119] Referring to FIGS. 8 through 10, it may be noted that the Sm-doped cerium oxide abrasive particles dispersed in the slurry composition of Example 1 may have a size distribution much narrower than that of undoped cerium oxide abrasive particles dispersed in the slurry composition of Comparative Example 1. It may also be noted that the slurry composition including the Sm-doped cerium oxide abrasive particles may have the reduced amounts of fine particles smaller than a mean particle size and large particles greater than about a mean particle size. These results may be caused by a relatively strong fracture strength and/or a sphere-like grain shape of Sm-doped cerium oxide abrasive particles such that a generation of fine particles or debris may be suppressed during a grinding process. At least due to the strong fracture strength, the particles may be broken along the crystal shape, and a highly uniform abrasive particle may be obtained.

Evaluation of Polishing Characteristics of Slurry Compositions

[0120] Polishing characteristics of the slurry compositions prepared in Example 1 and Comparative Example 1 were evaluated. A polishing rate of a silicon oxide layer and the number of scratches were measured. The silicon oxide layer was prepared by depositing PE-TEOS on a bare silicon wafer with a thickness of about 12,000 Å. Mirra (manufactured by AMAT in U.S.A.) was used as a polishing apparatus. A down pressure of a polishing pad was about 3.0 psi, a rotational speed of a table was about 108 rpm, a rotational speed of a head holding the silicon wafer was about 102 rpm, a polishing time was about 60 seconds, and a flow rate of the slurry composition was about 150 mL per minute.

[0121] After performing the polishing process, the silicon wafer was cleaned using a hydrogen fluoride (HF) aqueous solution diluted with a volume ratio of 100:1 (DIW:HF). The number of scratches was analyzed using a defect detector (AIT-UV). The total number of scratches and the number of deep scratches were measured. The results relating to the polishing rate are shown in Table 3 below, and the results relating to the number of scratches are shown in Table 4 below.

TABLE 3

	Polishing rate of oxide layer [Å/min]	Error range [Å/min]
Example 1	2,480	105
Comparative Example 1	2,600	125

TABLE 4

	Total number of scratches	Number of deep scratches
Example 1	250	3
Comparative Example 1	700	18

[0122] Referring to Tables 3 and 4, the slurry composition including the Sm-doped cerium oxide abrasive particles prepared in Example 1 showed a slightly reduced polishing rate of the silicon oxide layer, as compared with the slurry composition including undoped cerium oxide abrasive particles prepared in Comparative Example 1. It may be noted that there is not a significant difference in the polishing efficiency.

[0123] The slurry composition including the Sm-doped cerium oxide abrasive particle prepared in Example 1 may greatly reduce scratch defects. The slurry composition including undoped cerium oxide abrasive particles prepared in Comparative Example 1 generated about 700 scratches in total and about 18 deep scratches, whereas the slurry composition including the Sm-doped cerium oxide abrasive particles prepared in Example 1 generated about 250 scratches in total and about 3 deep scratches. It may be noted that the composition of Example 1 may reduce the total number of scratches by about 64%, and the number of deep scratches by about 83%, as compared with the composition of Comparative Example 1. Accordingly, it may be noted that doping a cerium oxide abrasive particle with a rare earth element may greatly reduce the number of scratches on a surface of an object to be polished.

[0124] Additionally, a polishing process for forming an isolation layer in a trench was performed using the slurry compositions prepared in Example 1 and Comparative Example 1. A trench was formed in a silicon wafer, and then a silicon oxide layer on the silicon wafer to fill the trench. The silicon oxide layer was formed using PE-TEOS. A CMP process was performed on the silicon oxide layer to form an isolation layer in the trench. A width of the trench was about 70 nm. The polishing process was performed under conditions substantially the same as those in the polishing process relating to Table 3 and 4. After performing the polishing process, the number of scratches was measured using a defect detector (AIT-UV). The total number of scratches and the number of deep scratches were measured. The results relating to the number of scratches are shown in Table 5 below and FIGS. 11 and 12. FIGS. 11 and 12 are wafer maps illustrating a distribution of scratch defects on a wafer polished using each of the slurry compositions obtained in Example 1 and Comparative Example 1.

TABLE 5

	Total number of scratches	Number of deep scratches
Example 1	9	3
Comparative Example 1	19	16

[0125] Referring to Table 5 and FIGS. 11 and 12, the slurry composition including the Sm-doped cerium oxide abrasive particles prepared in Example 1 may reduce scratch defects on a surface of the isolation layer, as compared with undoped cerium oxide abrasive particles. Particularly, the slurry composition including the Sm-doped cerium oxide abrasive par-

ticles prepared in Example 1 may greatly reduce deep scratches on the isolation, since the Sm-doped cerium oxide abrasive particles have a sphere-like grain shape and a substantially reduced amount of large particles.

Evaluations of Amounts of Large Particles and the Number of Scratches According to Doping Amount of a Rare Earth Element

[0126] The amounts of large particles dispersed in the slurry compositions prepared in Examples 2 through 6 and Comparative Example 2 were measured, and the number of scratches was also measured. The amount of large particles larger than about 2 μm was measured by a quantitative filtration method (QFM). The polishing process was performed on a silicon oxide layer, which was prepared by depositing PE-TEOS on a bare silicon wafer with a thickness of about 12,000 Å. Mirra (manufactured by AMAT in U.S.A.) was used as a polishing apparatus. A down pressure of a polishing pad was about 3.0 psi, a rotational speed of a table was about 108 rpm, a rotational speed of a head holding the silicon wafer was about 102 rpm, a polishing time was about 60 seconds, and a flow rate of the slurry composition was about 150 mL per minute. After performing the polishing process, the silicon wafer was cleaned using an HF aqueous solution diluted with a volume ratio of 100:1 (DIW:HF). The number of scratches was analyzed using a defect detector (AIT-UV). The total number of scratches and the number of deep scratches were measured. The relative ratio of scratches was evaluated, based on the number 100% of scratches generated using the slurry composition prepared in Comparative Example 2. The results are shown in Table 6 below and FIG. 13. FIG. 13 is a graph showing the number of scratches generated on a wafer according to the doping amount of the rare earth element.

TABLE 6

	Abrasive Particles		Mean Diameter [nm]	Large Particles [$>2 \mu\text{m}$, ppm]	Scratches	
	Sm [mol %]	Ce [mol %]			Number	Relative Ratio [%]
Example 2	30	70	120	54	8	25
Example 3	25	75	120	65	8	25
Example 4	20	80	120	103	12	37
Example 5	10	90	120	158	15	47
Example 6	5	95	120	182	24	75
Comparative Example 2	0	100	120	210	32	100

[0127] Referring to Table 6 and FIG. 13, it can be noted that the slurry composition including the Sm-doped cerium oxide abrasive particle has a relatively small amount of large particles, as compared with the slurry composition including the undoped cerium oxide abrasive particle. The composition of Comparative Example 2 included about 210 ppm of large particles greater than about 2 μm , whereas the composition of Examples 2 through 6 included at most about 182 ppm of large particles greater than about 2 μm . When the amount of samarium is greater than or equal to about 10% by mole, the amount of large particles greater than about 2 μm was about 158 ppm or less. Such an amount of large particles may reflect a decrease of at least about 25%, based on the amount of large particles in the case of using the undoped cerium oxide abrasive particles.

[0128] Further, doping the cerium oxide abrasive particles with the rare earth element may greatly reduce the number of scratches. When the amount of samarium is greater than or equal to about 10% by mole, the number of scratches generated on a surface of the polished object may be reduced with at least about 50%.

[0129] According to exemplary embodiments, the slurry composition includes a cerium oxide abrasive particle doped with a rare earth element. The cerium oxide abrasive particle doped with a rare earth element may have proper shape and/or size for reducing generation of a scratch defect on a surface of an object as compared with a pure cerium oxide abrasive particle. The cerium oxide abrasive particle doped with a rare earth element may have an improved fracture strength so that generation of debris or fine particles may be reduced during a grinding process and the amount of a large or agglomerated particle dispersed in the slurry composition may also be reduced. The slurry composition may reduce generation of a defect (e.g., a scratch) on an object by employing such an abrasive particle having a controlled shape and size of a crystal grain and a narrow distribution of a particle diameter.

[0130] The foregoing is illustrative of exemplary embodiments and is not to be construed as limiting thereof. Although a few exemplary embodiments have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings of the embodiments. Accordingly, all such modifications are intended to be included within the scope of the present invention as defined in the claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it may be to be understood that the foregoing may be illustrative of various example embodiments and is not to be construed as limited to the specific example embodiments disclosed, and that modifications to the disclosed example embodiments, as well as other example embodiments, are intended to be included within the scope of the appended claims.

1-14. (canceled)

15. A method of chemically and mechanically polishing an object, comprising:

providing a slurry composition between an object and a polishing pad, the slurry composition including a cerium oxide abrasive particle having a rare earth element as a dopant, and an aqueous medium for dispersing the cerium oxide abrasive particle, with the proviso that the rare earth element is not cerium; and

polishing a surface of the object by contacting the object with the polishing pad.

16. The method of claim 15, wherein the object comprises: a substrate having a trench; and an insulation layer on the substrate to fill the trench.

17. The method of claim 16, wherein polishing the surface of the object comprises polishing the insulation layer until an upper face of the substrate is exposed to form an isolation layer in the trench.

18. The method of claim 15, wherein the object comprises: a substrate on which a conductive structure is formed; and an insulating interlayer on the substrate to cover the conductive structure.

19. The method of claim 1, wherein the rare earth element comprises samarium (Sm).

20. The method of claim **1**, wherein an amount of the rare earth element is in a range of about 10 to about 40% by mole, based on a total mole of cerium and the rare earth element.

21. The method of claim **20**, wherein the amount of the rare earth element is in a range of about 20 to about 30% by mole, based on a total mole of cerium and the rare earth element.

22. The method of claim **1**, wherein the cerium oxide abrasive particle has a mean grain diameter of less than about 29 nm.

23. The method of claim **1**, wherein the ceria abrasive particle has a mean diameter of a secondary particle in a range of about 70 nm to about 120 nm.

24. The method of claim **1**, wherein the cerium oxide abrasive particle doped with the rare earth element has a sphere-like grain.

25. The method of claim **1**, wherein the aqueous medium comprises a dispersing agent and water, and an amount of the dispersing agent is in a range of about 0.05 to about 5% by weight, based on a total weight of the slurry composition.

26. The method of claim **1**, wherein an amount of the cerium oxide abrasive particle is in a range of about 1 to about 10% by weight, based on a total weight of the slurry composition.

27. The method of claim **1**, wherein the cerium oxide abrasive particle is prepared by performing a thermal treatment on a precipitate obtained by co-precipitating a cerium salt and a salt of a rare earth element in an aqueous solution, and by grinding the thermally treated precipitate, with the proviso that the rare earth element is not cerium.

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